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Ground-Water Quality in Quaternary Deposits of the Central High Plains Aquifer, South-Central Kansas, 1999

By L. M. Pope, B. W. Bruce, and C. V. Hansen.



Reno County, (photograph by L.M. Pope, USGS)

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
foot (ft)	0.3048	meter
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	2.54	centimeter
meter (m)	3.281	foot
microgram per liter ($\mu\text{g/L}$)	1.0	part per billion
micrometer (μm)	0.00003937	inch
mile (mi)	1.609	kilometer
milligram per liter (mg/L)	1.0	part per million
milliliter (mL)	0.0338	ounce, fluid
pound per acre (lb/acre)	1.121	kilogram per hectare
pound per square inch (lb/in ²)	6.895	kilopascal
square mile (mi ²)	2.590	square kilometer
ton	0.9072	megagram

Temperature can be converted to degrees Celsius ($^{\circ}\text{C}$) or degrees Fahrenheit ($^{\circ}\text{F}$) by the equations:

$$\begin{aligned}\div C &= 5/9 (\div F - 32) \\ \div F &= 9/5 (\div C) + 32.\end{aligned}$$

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be made. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study areas, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study units and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

Abstract

Water samples from 20 randomly selected domestic water-supply wells completed in the Quaternary deposits of south-central Kansas were collected as part of the High Plains Regional Ground-Water Study conducted by the U.S. Geological Survey's National Water-Quality Assessment Program. The samples were analyzed for about 170 water-quality constituents that included physical properties, dissolved solids and major ions, nutrients and dissolved organic carbon, trace elements, pesticides, volatile organic compounds, and radon. The purpose of this study was to provide a broad overview of ground-water quality in a major geologic subunit of the High Plains aquifer.

Water from five wells (25 percent) exceeded the 500-milligrams-per-liter of dissolved solids Secondary Maximum Contaminant Level for drinking water. The Secondary Maximum Contaminant Levels of 250 milligrams per liter for chloride and sulfate were exceeded in water from one well each. The source of these dissolved solids was probably natural processes.

Concentrations of most nutrients in water from the sampled wells were small, with the exception of nitrate. Water from 15 percent of the sampled wells had concentrations of nitrate greater than the 10-milligram-per-liter Maximum Contaminant Level for drinking water. Water from 80 percent of the sampled wells showed nitrate enrichment (concentrations greater than

2.0 milligrams per liter), which is more than what might be expected for natural background concentrations. This enrichment may be the result of synthetic fertilizer applications, the addition of soil amendment (manure) on cropland, or livestock production.

Most trace elements in water from the sampled wells were detected only in small concentrations, and few exceeded respective water-quality standards. Only arsenic was detected in one well sample at a concentration (240 micrograms per liter) that exceeded its proposed Maximum Contaminant Level (5.0 micrograms per liter). Additionally, one concentration of iron and two concentrations of manganese were larger than the Secondary Maximum Contaminant Levels of 300 and 50 micrograms per liter, respectively. Some occurrences of trace elements may have originated from human-related sources; however, the generally small concentrations that were measured probably reflect mostly natural sources for these constituents.

A total of 47 pesticide compounds from several classes of herbicides and insecticides that included triazine, organophosphorus, organochlorine, and carbamate compounds and three pesticide degradation products were analyzed in ground-water samples during this study. Water from 50 percent of the wells sampled had detectable concentrations of one or more of these 47 compounds. The herbicide atrazine and its degradation product deethylatrazine were detected most frequently (in water from eight and nine wells, respectively); other pesticides detected were the insecticides carbofuran (in water from one well) and diazinon (in water from one well), and the herbicide metolachlor (in water from two wells). However, all concentrations of these compounds were small and substantially less than established Maximum Contaminant Levels.

The use of pesticides in crop production probably is largely responsible for the occurrence of pesticides in the ground-water samples collected during this study. Although concentrations of detected pesticides were small (relative to established Maximum Contaminant Levels), the synergistic effect of these concentrations and long-term exposure to multiple pesticides on human health are unknown.

Water samples from the Quaternary deposits were analyzed for 85 volatile organic compounds. Water from two wells (10 percent) had a detectable concentration of a volatile organic compound. Chloroform was detected at concentrations of 0.18 and 0.25 microgram per liter, substantially less than the 100-microgram-per-liter Maximum Contaminant Level for total trihalomethanes. In general, the occurrence and detection of volatile organic compounds were infrequent, detectable concentrations were substantially less than established Maximum Contaminant Levels, and the areal

distribution of volatile organic compounds in ground water was extremely limited.

Concentrations of radon were detected in water from every well sampled and ranged from 200 to 590 picocuries per liter with a median concentration of 260 picocuries per liter. Radon concentrations in water from 30 percent of the wells were larger than the proposed 300-picocuries-per-liter Maximum Contaminant Level.

Introduction

Knowledge of the quality of the Nation's water resources is important because of implications for human and aquatic health and because of the substantial costs associated with land and water management, conservation, and regulation. In 1991, the U.S. Geological Survey (USGS) began full implementation of the National Water-Quality Assessment (NAWQA) Program. The long-term goals of the NAWQA Program are to describe the status and trends in the quality of the Nation's surface- and ground-water resources and to determine the natural and human-related factors affecting water quality (Gilliom and others, 1995). More than 50 major river basins or aquifer systems have been identified for investigation by the NAWQA Program. Together, these basins and aquifer systems include water resources available to more than 60 percent of the population and cover about one-half of the land area in the conterminous United States.

NAWQA ground-water studies include a component designed to assess the occurrence and distribution of water-quality constituents for regionally important aquifer systems. Individual studies of ground-water quality are completed in smaller hydrogeologic subunits within a regional aquifer. Completion of multiple subunit surveys within a single regional aquifer systematically evaluates the quality of water resources for an entire study area.

The High Plains Regional Ground-Water Study was begun in June 1998 and represents a modification of the traditional NAWQA design in that the ground-water resource is the primary focus of investigation. The High Plains aquifer is a nationally important water resource that underlies about 174,000 mi² in parts of eight Western States ([fig. 1](#)). About 20 percent of all agricultural land in the United States is in the High Plains, and about 30 percent of all the ground water used for irrigation in the United States is pumped from this aquifer (Weeks and others, 1988).

The High Plains aquifer can be divided into local hydrogeologic subunits; the primary subunit being the Ogallala Formation that comprises about 70

percent of the High Plains aquifer. Other hydrogeologic subunits also can be very important local water resources. In the central High Plains ([fig. 1](#); parts of Colorado, Kansas, New Mexico, Oklahoma, and Texas), the nonglacial deposits of Quaternary age (hereafter referred to as Quaternary deposits) in south-central Kansas are an important local source of water for both agriculture and public supply. The Quaternary deposits underlie an area of about 7,000 mi². Depth to water in these deposits is generally less than 100 ft and, in many places, less than 30 ft (Woods and others, 1997). This part of the High Plains also is more populated than other parts of the central High Plains with major cities (and their 1990 populations) being Hutchinson (39,000), Great Bend (15,000), and McPherson (12,000), and several other cities over 5,000 in population (Helyar, 1994). Wichita (population of 304,000) lies generally southeast of the High Plains, but some of the urban area lies within the boundary of the Quaternary deposits and the city gets much of its municipal water supply from these deposits.

Water in the Quaternary deposits is vulnerable to effects from land-surface activities. Shallow depths to water, lack of a geologic barrier to slow downward migration of contaminants, and large hydraulic conductivities of these deposits contribute to the potential for degradation of water quality in this aquifer. Residential and urban land uses, agriculture, and oil and gas exploration/development are potential sources of contaminants to this aquifer. As part of the High Plains NAWQA study, the occurrence and distribution of chemical constituents within these Quaternary deposits were determined.

Purpose and Scope

The purpose of this report is to provide a broad-scale assessment of groundwater quality in Quaternary deposits of the central High Plains aquifer in south-central Kansas ([fig. 1](#)). Water samples from 20 randomly selected domestic water-supply wells were analyzed for about 170 water-quality constituents, including physical properties, dissolved solids and major ions, nutrients and dissolved organic carbon, trace elements, pesticides, volatile organic compounds (VOC's), and radon. Many of these constituents are regulated in public drinking-water supplies by the U.S. Environmental Protection Agency (USEPA). The constituents will be discussed relative to USEPA drinking-water standards as a frame of reference.

Acknowledgments

The cooperation of many individuals and organizations was essential for the completion of this study. The authors appreciate the permission granted by well owners for collection of water samples. Also acknowledged are: the

Kansas Geological Survey (Lawrence, Kansas) for sharing drillers' logs and water-well data; Mike Dealy, *Equus* Beds Groundwater Management District No. 2 (Halstead, Kansas), and Sharon Falk, Big Bend Groundwater Management District No. 5 (Stafford, Kansas), for sharing their information and experience pertaining to the study area; Mike Carlson and Carol Carlson (USGS) for collection of water-quality samples; Lesley Red Boy (USGS) for data processing; and Lanna Combs, Mike Kemppainen, Jeff Hartley, and Kristi Hartley (USGS) for editorial review, preparation of illustrations, and processing of this report.

Description of Study Area

The study area, as described in this report, includes only the Quaternary deposits in south-central Kansas that are a subunit of the High Plains aquifer as mapped by Gutentag and others (1984) ([fig. 1](#)). The study area includes all or parts of 21 counties.

Hydrogeologic Setting

The hydrogeologic setting of the study area has been described in detail by Williams and Lohman (1949), Fader and Stullken (1978), Gutentag and others (1984), and Stullken and others (1987). Generally, Quaternary deposits in the study area consist of unconsolidated sand and gravel with thin, interspersed layers of silt and clay.

Water in the Quaternary deposits is derived mainly from precipitation and irrigation return flow although the density of irrigation wells in south-central Kansas is much less than in other areas of the High Plains aquifer (Gutentag and others, 1984). The Quaternary deposits were deposited by fluvial (stream-deposited) and eolian (windblown) processes during the past 2 million years. The ground water is unconfined, and regional flow is from west to east. The thickness of saturated material ranges from less than 100 to about 400 ft with potential well yields ranging from less than 250 to more than 750 gal/min (Gutentag and others, 1984).

Land Use and Agricultural Production

Land use in the study area ([fig. 2](#)) is typical of this major agricultural region in the Midwestern United States. Cropland and grassland (pasture and rangeland) dominate the area. Major crops include corn, sorghum, soybeans, sunflowers, and wheat ([fig. 3](#)). Wheat is, by far, the dominant crop in the area overlying the Quaternary deposits in south-central Kansas. On average, about 70 percent of the cropland in each county is used for the production of wheat, followed by sorghum (17 percent), corn (8 percent), soybeans (5

percent), and sunflowers (less than 1 percent) (Kansas Department of Agriculture and U.S. Department of Agriculture, 1999). Agricultural-production and water-use data from Marion and Ness Counties were not used in this report because of the small areas of Quaternary deposits that occur in those counties.

Grassland in the study area generally is used, directly or indirectly, for livestock production. Much of the grassland is pasture or rangeland used for cattle and calf production. Areas not pastured, typically, are used for the production of hay that subsequently is used as winter feed for cattle on grassland or in confined feeding operations. Cattle and calf production is an important part of the farm economy in the study area although its importance varies from county to county ([fig. 4](#)). Cattle and calf inventories, as of January 1, 1998, varied from 22,000 head in Rush County to 124,000 head in Barton County. In addition to cattle and calves, there were about 133,000 hogs and pigs (inventoried December 1, 1997) and 34,000 sheep and lambs (inventoried January 1, 1998) in the study area (Kansas Department of Agriculture and U.S. Department of Agriculture, 1999).

Water Use

Ground water is the source of about 91 percent of the water withdrawn in the study area (Joan Kenny, USGS, written commun., 1999). Ground- and surface-water withdrawals during 1997 were 613,000 and 63,000 acre-ft, respectively. Irrigation, which accounted for about 80 percent of the withdrawals, was the largest use of ground water in the study area ([fig. 5](#)). Municipal use accounted for about 10 percent of the ground-water withdrawals ([fig. 5A](#)). Ground-water withdrawals for municipal use were largest in Harvey, Reno, and Sedgwick Counties ([fig. 5B](#)) and were used mainly to supply the two largest cities in and near the study area-Hutchinson and Wichita. Industrial uses accounted for about 7 percent of ground-water withdrawals ([fig. 5A](#)) and were largest in Reno and Sedgwick Counties ([fig. 5B](#)). Salt production, sand and gravel operations, and manufacture of aircraft, paperboard, and chemicals (Kenny, 1999) accounted for most of the industrial water use in the study area.

Although representing only about 9 percent of the water withdrawn in the study area, surface-water withdrawals included substantial quantities of water used for municipal supplies and for recreation (Joan Kenny, USGS, written commun., 1999). For example, surface-water withdrawals from Cheney Reservoir in Sedgwick County ([fig. 4](#)) currently (2000) provide about one-half of Wichita's municipal supplies. Municipal-use surface-water withdrawals in Sedgwick County were about 34,000 acre-ft in 1997 (Lane Letourneau, Kansas Department of Agriculture, oral commun., 2000).

Methods of investigation

The study design of ground-water quality in Quaternary deposits in south-central Kansas followed the NAWQA protocols described by Gilliom and others (1995) and Lapham and others (1995). Delineation of the study-area boundaries was based on work completed as part of the USGS Regional Aquifer-System Analysis (RASA) Program (Sun and Johnston, 1994). The High Plains RASA, which described the quantity and movement of ground-water resources in the High Plains, determined the boundaries of the High Plains aquifer and the various hydrogeologic subunits included in the aquifer (Gutentag and others, 1984). The boundary of the Quaternary deposits in south-central Kansas was taken from Gutentag and others (1984), with the boundary drawn to include nonglacial deposits in areas where they do not overlie aquifer units of Tertiary age.

Well Selection

Within the study area, potential ground-water sampling sites were selected using a grid-based random site-selection computer program (Scott, 1990). Twenty potential sampling sites were required for that part of the Quaternary deposits where saturated sediment existed (about 7,000 mi²). One primary and one alternate site were randomly selected within the equal-area polygons containing each of the 20 sites. The alternate site was identified in the event that no well suitable for sampling could be identified within a 4-mi radius of the primary site. However, none of the alternate sites were needed for this study. The distribution of potential sampling locations represented a density of one primary site for each 350 mi². The average distance between primary sites was about 19 mi.

Domestic wells suitable for sampling were identified near each primary site to achieve a distribution of sampling wells throughout the study area. Domestic wells were chosen for this study because domestic wells (1) provide excellent areal and depth coverage in the Quaternary deposits; (2) are, generally, easily accessible under all weather conditions; and (3) have low-capacity pumping rates that limit the potential for withdrawal of water from formations other than the Quaternary deposits. A well was considered suitable for sampling if (1) it was within a 4-mi radius of the randomly selected site; (2) it was a domestic well that was actively being used as a household drinking-water supply; (3) it could be determined from a drilling log or other means that the well was indeed completed in Quaternary deposits; (4) substantial information could be obtained indicating the construction details of the well, including well depth, screened interval, and casing information; and (5) it was possible to collect a water sample prior to

any type of water treatment or storage, such as filtration or residence in a pressure tank or cistern.

[Figure 6](#) shows the distribution of domestic-supply wells sampled. Well depths ranged from 50 to 160 ft. Depths to water at the time of sampling ranged from about 12 to about 93 ft below land surface, with a median depth of about 30 ft. More detailed information about the construction of individual wells is provided in table 1.

Table 1. Selected well-construction details for sampled domestic water-supply wells completed in Quaternary deposits, south-central Kansas

[BLS, below land surface; PVC, polyvinyl chloride]

Map index number (fig. 6)	Date of installation (month-day-year)	Depth of completed well BLS (feet)	Depth to water BLS at time of sampling, except as noted (feet)	Screened interval BLS (feet)	Casing material	Casing joints	Casing diameter (inches)	Grout material
101	05-20-97	160	92.9	120-160	PVC	Glued	5	Cement
102	02-06-80	156	91.8	136-156	PVC	Glued	5	Bentonite
103	03-22-88	72	13.7	52-72	PVC	Glued	5	Bentonite
104	09-20-93	65	29.8	45-65	PVC	Glued	5	Bentonite
105	05-24-83	70	30.8	54-70	PVC	Glued	5	Neat cement
106	09-15-86	90	15.5	70-90	PVC	Glued	5	Neat cement
107	01-30-97	70	15.1	55-70	PVC	Glued	5	Bentonite
108	01-21-86	91	61.0	81-91	PVC	Glued	5	Neat

								cement
109	09-16-94	157	82.0	115-120 145-157	PVC	Glued	5	Bentoni te
110	05-09-94	64	15.0	45-55	PVC	Glued	5	Bentoni te
111	12-16-97	50	20.6	26-32	PVC	Glued	5	Bentoni te
112	04-12-95	74	21.6	64-74	PVC	Glued	5	Bentoni te
113	11-17-92	73	112.0	63-73	PVC	Glued	5	Bentoni te
114	03-19-85	114	87.9	90-110	PVC	Glued	5	Neat cement
115	06-06-95	78	21.4	65-78	PVC	Glued	5	Bentoni te
116	07-26-88	88	32.5	78-88	PVC	Glued	5	Cemen t
117	01-14-91	59	43.6	49-59	PVC	Glued	6	Bentoni te
118	05-19-97	61	23.2	50-61	PVC	Glued	5	Bentoni te
119	04-20-77	105	33.2	90-105	PVC	Glued	5	Neat cement
120	11-12-98	70	16.8	50-70	PVC	Glued	5	Bentoni te

Sample Collection and Analysis

The 20 domestic water-supply wells were sampled from May 26 to June 29, 1999, for this assessment of ground-water quality. Each well was sampled once. Ground-water samples were collected and processed in a mobile water-quality laboratory mounted on a four-wheel-drive truck. Existing submersible pumps, permanently installed in each domestic well, were used to deliver water to the land surface. In most cases, a permanent spigot or hydrant near the wellhead was used as the water-quality sampling point. Occasionally, plumbing connections near the wellhead were modified temporarily for sampling purposes. All materials in contact with the water sample after the existing plumbing consisted of either stainless steel or Teflon.

Sampling protocols followed during this study are described in detail in Koterba and others (1995). To minimize the risk of sample contamination, all sample collection and preservation took place in dedicated environmental chambers consisting of clear polyethylene bags supported by tubular polyvinyl chloride (PVC) frames. Sampling equipment extending from the permanent sampling point near the wellhead to the sampling chamber inside the mobile laboratory, was decontaminated thoroughly between each sample collection using a progression of nonphosphate detergent wash, tap-water rinse, methanol rinse, and final deionized-water rinse. Polyethylene bags forming the sample and preservation chambers were replaced between each sample collection.

Sampled wells were first purged of possible stagnant water. During the initial pumping period, measurements of specific conductance, pH, water temperature, and dissolved oxygen were monitored every 5 minutes in a closed-cell, flow-through chamber until stable readings were obtained. Turbidity also was measured every 5 minutes using a portable turbidity meter. Once stable readings of these physical properties were obtained, water flow inside the laboratory was redirected to the clean sampling chamber where sample water was immediately collected for analysis. Constituents analyzed in water samples collected from each well are listed in [table 4](#) in the "Supplemental Information" section at the back of this report.

Samples for the analysis of major ions, nutrients, and trace elements were filtered through a 0.45-mm pore-size disposable-capsule filter and collected in precleaned plastic bottles that were rinsed onsite with filtered ground water. Samples to be analyzed for concentrations of major cations and trace elements were preserved to less than pH 2.0 using ultrapure nitric acid. A filtered, unpreserved sample was collected for major anions. Additionally, a filtered sample was collected for onsite titration of carbonate alkalinity. An unfiltered sample for laboratory measurements of specific conductance and pH was filled in the sampling chamber directly and was not preserved. Nutrient samples were filtered (0.45-mm pore size) into onsite-rinsed brown plastic bottles and were chilled on ice, with no preservation, until delivery to the laboratory for analysis.

To avoid contact between water sampled for dissolved organic carbon (DOC) and any methanol-rinsed sampling equipment (a possible source of DOC contamination), samples were collected directly from the permanent water-sampling point close to the wellhead. The sample was captured in a stainless-steel pressure-filtration funnel equipped with a 0.45-mm pore-size silver filter. Trace concentrations of silver imparted by the filter served as a preservative for the DOC sample. Water samples were forced through the silver filter using purified nitrogen gas at a pressure not exceeding 15 lb/in².

As with other organic samples, the water was collected in a cleaned and baked amber glass bottle and immediately chilled on ice until delivery to the laboratory for analysis.

Water samples collected for pesticide analyses were passed through a methanol-rinsed, stainless-steel filter chamber containing a cleaned and baked 0.7-mm pore-size glass-fiber filter. All samples analyzed for organic constituents were collected in amber-colored glass bottles and immediately chilled on ice until delivery to the laboratory for analysis. Unfiltered water for analysis of VOC's was collected in precleaned 40-mL septum vials with no headspace and preserved to less than pH 2.0, using one to five drops of specially prepared 1:1 hydrochloric acid.

Because radon is a gas that may escape from water samples if exposed to the atmosphere and because water samples may be contaminated by radon already present in the atmosphere, samples for the analysis of radon were collected inside the mobile laboratory vehicle using an in-line back-pressured sampling septum and syringe. Bubble-free samples were drawn through the sampling septum using a gas-tight syringe. Radon samples were injected into glass scintillation vials below a mineral-oil mixture designed to exchange and trap radon from the water sample. The scintillation vials then were vigorously shaken for 15 seconds to promote transfer of radon to the mineral-oil mixture.

Analysis of all water-quality samples was performed at the USGS National Water-Quality Laboratory (NWQL) in Lakewood, Colorado. Table 2 lists references for the analytical methods used for each analysis. Analytical data collected for this study are listed in [table 5](#) in the "Supplemental Information" section at the back of this report.

Table 2. Laboratory analysis methods for measured water-quality constituents

[USGS, U.S. Geological Survey; UV, ultraviolet; C, carbon; GC/MS, gas chromatography/mass spectrometry]

Constituent or constituent group	Analysis method	Method reference
Major ions (USGS schedule 2750)	Atomic absorption spectrometry	Fishman (1993)
Nutrients (USGS schedule	Various methods	Fishman (1993)

2752)

Dissolved organic carbon (USGS schedule 2085)	UV-promoted persulfate oxidation and infrared spectrometry	Brenton and Arnett (1993)
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Trace elements (USGS schedule 2703)	Atomic absorption spectrometry	Faires (1993)
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Pesticides (USGS schedule 2001)	Solid-phase extraction using a C-18 cartridge and GC/MS	Zaugg and others (1995)
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Volatile organic compounds (USGS schedule 2020)	Purge and trap capillary- column GC/MS	Connor and others (1998)
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Radon (USGS laboratory code 1369)	Liquid scintillation	American Society for Testing and Materials (1996)
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Quality-Control Data

Quality-control data to test sample collection, processing, and analysis were collected at a frequency of about 30 percent of the environmental ground-water samples collected from wells. Quality-control samples included field blank samples, replicate environmental samples, and field-matrix spike samples. Field-blank samples verified that decontamination procedures were adequate and that onsite and laboratory protocols did not contaminate the samples. Replicate samples assess the combined effects of onsite and laboratory procedures on measurement variability. Matrix-spiked samples were analyzed to test for bias and variability from ground-water matrix interference or degradation of constituent concentration during sample processing, storage, and analysis.

Field-blank samples were analyzed for concentrations of major ions, nutrients and dissolved organic carbon, trace elements, pesticides, and VOC's. The source solution for field-blank samples was specially prepared organic-free or inorganic-free water provided by the USGS NWQL for the NAWQA Program. Field-blank solution was passed through all sampling equipment, and samples were collected using the same protocols as for environmental samples.

Few water-quality constituents were detected in the field-blank samples. Ammonia and orthophosphate were each detected in one of two field-blank samples at concentrations slightly greater than the analytical method reporting limits ([table 4](#) at the back of this report). Aluminum and dissolved organic carbon were detected in each of two field-blank samples at mean concentrations of 4.2 µg/L and 0.35 µg/L, respectively. None of the pesticides listed in [table 4](#) were detected in the field-blank samples. Styrene was the only VOC ([table 4](#)) detected in field-blank samples. Styrene was detected in two of four samples. The analytical results of field-blank samples indicate that the decontamination procedures used during this study were adequate and that onsite and laboratory contamination of environmental samples was minimal.

Two sets of replicate environmental samples were collected sequentially during this study for all analyses except pesticides and VOC's. Replication of pesticides and VOC's was accomplished during the field-matrix spiking process wherein replicate environmental samples were injected with known concentrations of selected pesticides or VOC's.

Relative analytical variation between reported concentrations of replicate environmental samples was calculated for the major ions, nutrients, dissolved organic carbon, and trace elements listed in [table 4](#). The variation, as a percentage, between constituent concentrations of replicate environmental samples was calculated as the absolute value of 100 multiplied by the difference in replicate concentrations divided by the summation of replicate concentrations. Relative analytical variation was not calculated if one or both analyses for a replicate pair were less than analytical method reporting limits.

For most replicated constituents, the relative analytical variation was less than 2 percent. Relative percentage variation was less than 5 percent for all constituents except ammonia (9.6 percent, one replicate pair), dissolved organic carbon (16.7 percent, one replicate pair), and arsenic (25.6 and 15.0 percent). Generally, however, the results of replicate environmental sample analyses indicate an acceptable degree of laboratory precision and reproducibility.

Analytical recovery bias and variability were assessed for the pesticides listed in [table 4](#) using analyses of three field-matrix spike samples collected during this study. Replicate environmental samples were spiked with known amounts of pesticides and analyzed according to methods listed in table 2. Percentage recoveries were calculated as 100 multiplied by the analytically determined concentration in the field-matrix spike sample divided by the

summation of the expected (calculated) spike concentration plus the analytically determined concentration in the primary environmental sample.

Mean percentage recoveries for pesticides listed in [table 4](#) generally were biased low (less than 100-percent recovery). Of 47 pesticides, 38 had mean percentage recoveries less than 100 percent, with a few (azinphos-methyl, cis-permethrin, deethylatrazine, and p,p'-DDE) with mean percentage recoveries less than 70 percent. In contrast, carbofuran, linuron, tebuthiuron, and terbacil had an unusually high mean percentage recovery (equal to or greater than 130 percent).

These data indicate that sample processing and analytical methods provided a reasonable approximation of expected pesticide concentrations for most of the pesticides listed in [table 4](#). For example, 27 of the 47 listed pesticides had mean percentage recoveries between 90 and 110 percent, and from a study-area perspective, mean percentage recoveries for most of the pesticides that might occur in ground water in agriculturally dominated south-central Kansas were within this range. On the basis of crops grown and pesticides commonly applied, these pesticides included acetochlor, alachlor, atrazine, diazinon, and metolachlor (Kansas State University, 1991; Regehr and others, 1994).

Percentage recoveries for VOC's generally were less than those for pesticides. Mean percentage recoveries for the VOC's ([table 4](#)) ranged from 47.8 percent (2,2-Dichloropropane) to 112 percent (2-Butanone). The average mean percentage recovery for all 85 VOC's was 69.7 percent.

Ancillary Data

Ancillary data were collected for all wells from which water-quality data were obtained. The ancillary data included selected features or conditions of the sampling site, the well, the subsurface at the well, and the landscape and land-management activities in the vicinity of the well. These data subsequently become part of the NAWQA National Data Base Archive. Nationally consistent and quantitative methods for the collection, documentation, and compilation of ancillary data for this study are presented in Koterba (1998).

Ancillary data were divided into two parts and are maintained in two separate data bases. Site, well, and subsurface data are a part of the USGS National Water Information System-Ground-Water Site Inventory (GWSI) data base. Land-use, land-management, and other required landscape data are a part of a new Land-Use and Land-Cover Field Sheet (LULCFS) data base of the NAWQA Program.

The required GWSI data for NAWQA wells are listed in Koterba (1998, table 1, p. 5-8). These data include precise location information, well-construction details, and descriptions of the hydrogeologic unit and lithologic materials in which the well is installed. Because the study of Quaternary deposits in south-central Kansas used existing domestic water-supply wells, the GWSI data base was populated to the extent possible using information recorded on drillers' logs and well-construction records.

Data requirements for the LULCFS data base were designed to document land-surface activities that might affect ground-water quality. These data characterize potential point sources of ground-water contamination and areally extensive land-use practices with possible nonpoint-source effects. Nonpoint-source activities might include large areal applications of water or chemicals such as used in agricultural areas, or extensive industrial, commercial, or residential urban environments. These data generally were recorded onsite at the time of water-sample collection through observations of the area surrounding the well site.

GROUND-WATER QUALITY

The USEPA has established drinking-water standards for physical properties and chemical constituents that may have adverse effects on human health or that may affect the odor, appearance, or desirability of water (U.S. Environmental Protection Agency, 2000a). A Maximum Contaminant Level (MCL) is the maximum permissible level for a contaminant in drinking water that is delivered to any user of a public-water system. A Secondary Maximum Contaminant Level (SMCL) is a nonenforceable Federal guideline regarding aesthetic effects of drinking water. Ground-water quality in the Quaternary deposits of the central High Plains aquifer in south-central Kansas is discussed in the following sections in relation to these USEPA standards.

Physical Properties

Physical properties were measured in water from each of the 20 domestic water-supply wells sampled during this study ([table 5](#) at the back of this report). Measurements were made at the time of sample collection and included specific conductance, pH, water temperature, turbidity, dissolved oxygen, and alkalinity. A statistical summary and USEPA standards for physical properties in water from 20 domestic water-supply wells ([fig. 6](#)) sampled during this study are presented in table 3.

Table 3. Statistical summary and U.S. Environmental Protection Agency (2000a) drinking-water

standards for physical properties in water from 20 domestic water-supply wells completed in Quaternary deposits, south-central Kansas, 1999

[ÎS/cm, microsiemens per centimeter at 25 ÷C; ÷C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; CaCO₃, calcium carbonate; SMCL, Secondary Maximum Contaminant Level; MCL, Maximum Contaminant Level; --, not applicable]

Physical property (unit of measurement)	Number of samples	Concentration or measurement			Drinking- water standard
		Minimum	Median	Maximum	
Specific conductance (ÎS/cm)	20	173	490	1,760	--
pH (standard units)	20	6.4	7.2	7.6	6.5-8.5 (SMCL)
Water temperature (÷C)	20	14.8	16.2	17.7	--
Turbidity (NTU)	20	.10	.30	.80	5 (MCL)
Dissolved oxygen (mg/L)	20	.1	5.1	7.3	--
Alkalinity, water whole, field (mg/L as CaCO₃)	20	60	170	320	--

Water from most wells had specific conductance values less than 800 ÎS/cm (microsiemens per centimeter at 25 ÷C). The only samples with specific conductance values greater than 800 ÎS/cm were from wells 105 (1,010 ÎS/cm), 114 (1,280 ÎS/cm), and 117 (1,760 ÎS/cm). Specific conductance describes the ability of water to conduct an electrical current and provides an indication of ion concentrations. As conductance of the water increases, so does the ion concentration (Hem, 1985).

The pH of water from all except one sampled well was within the USEPA SMCL range of 6.5 to 8.5 standard units in drinking water. The exception was water from well 118, which had a pH of 6.4 standard units. pH values

less than 7.0 are indicative of acidic water, and values greater than 7.0 are indicative of alkaline water.

The turbidity (cloudiness) of water from all wells was low, which generally indicates not only an acceptable aesthetic appeal and a lack of obvious contamination but also that the wells were developed properly and that samples were representative of the aquifer water. Turbidity has no health effects, but it can interfere with disinfection and provide a medium for microbial growth. Excessive turbidity may indicate the presence of microbes (U.S. Environmental Protection Agency, 2000a).

Water from most of the wells was well oxygenated as indicated by a median dissolved-oxygen concentration of 5.1 mg/L (table 3). Water from two wells (wells 107 and 115), however, had unusually small dissolved-oxygen concentrations (0.2 and 0.1 mg/L, respectively, [table 5](#)). Oxygen enters ground water through recharge of oxygen-enriched water that percolates down through the unsaturated zone where it may react with oxidizable material encountered along the flow path of the water. The principal reacting species are organic material and reduced inorganic minerals such as pyrite and siderite (Hem, 1985). The small dissolved-oxygen concentrations in water from wells 107 and 115 may represent natural and localized, oxygen-demanding (reducing) conditions in the unsaturated zone or may be an indication of contamination from the distribution or disposal of organic material associated with human activities. This human-related material could be from synthetic fertilizers used in crop production, the distribution of animal manure as a soil amendment, or as leachate from confined animal-feeding operations or domestic septic systems.

Alkalinity as CaCO_3 (calcium carbonate) in water is a measure of the acid-buffering capacity of a filtered water sample. Alkalinity as CaCO_3 ranged from 60 to 320 mg/L in the ground-water samples collected (table 3). Water with excessive alkalinity as CaCO_3 may have a distinctive unpleasant taste, and irrigation water with excessive alkalinity may increase the pH of the soil solution, leach organic material, decrease permeability of the soil, and impair plant growth (Hem, 1985).

Dissolved Solids and Major Ions

Dissolved solids are an important indicator of water quality and, in uncontaminated ground water, are the result of natural dissolution of rocks and minerals. Dissolved solids are also an important indicator of the suitability of water for drinking, irrigation, and industrial use. Although drinking water containing more than 500 mg/L dissolved solids (USEPA SMCL) is undesirable, such water is used in many areas where less

mineralized water is not available. Dissolved solids in irrigation water may adversely affect plants directly by the development of high osmotic conditions in the soil solution and by the presence of phytotoxins.

The major constituents of dissolved solids in ground-water samples collected from Quaternary deposits in south-central Kansas are the cations (positively charged ions) calcium, magnesium, potassium, silica, and sodium and the anions (negatively charged ions) bicarbonate, bromide, chloride, fluoride, and sulfate. Sample concentrations, median values, and associated water-quality standards for dissolved solids and major ions are presented in [figure 7](#).

Concentrations of dissolved solids in water from the 20 domestic water-supply wells sampled ranged from 143 (well 118) to 1,060 mg/L (well 117) ([fig. 7](#), [table 5](#) at the back of this report). The distribution of dissolved-solids concentrations in water is shown in [figure 8](#). The median dissolved-solids concentration was 318 mg/L, substantially less than the 500-mg/L SMCL established by the USEPA (U.S. Environmental Protection Agency, 2000a). However, water from five wells (105, 111, 114, 115, and 117) did exceed the SMCL ([fig. 8](#)).

Generally, the data collected for this study ([table 5](#)) indicate that calcium bicarbonate type water is the dominant ground-water type in the Quaternary deposits area of south-central Kansas ([fig. 9](#)). However, major-ion composition can vary locally to sodium chloride type water (well 117), a mixed water type of calcium bicarbonate sulfate and sodium chloride (well 105), or a calcium and magnesium sulfate type water (well 114).

Associated with the variability in or mixing of water types, the concentrations of chloride in water from well 117 (350 mg/L) and sulfate in water from well 114 (290 mg/L) both exceed the 250-mg/L SMCL's for these constituents. Both of these concentrations were substantially larger than concentrations in water from the other wells. The chloride concentration in water from well 117 was more than three times larger than the next largest concentration (110 mg/L, well 105), and the sulfate concentration in water from well 114 was almost five times larger than the next largest concentration (59 mg/L, well 105).

The probable source of these large concentrations of chloride and sulfate may be natural salt (sodium chloride) contamination, which is known to occur in the area of well 105 (Buddemeier and others, 1995) or, in the case of sulfate, the oxidation of pyrite and other sulfides (common in sedimentary rocks) in well-oxygenated water or the dissolution of evaporite deposits such as gypsum (calcium sulfate). Although no human-health effects are

associated with chloride or sulfate in the concentration range determined during this study, concentrations larger than 250 mg/L may produce an objectionable taste in drinking water. Chloride may impart a salty taste to drinking water and may accelerate the corrosion of metals used in water-supply systems. Chloride in irrigation water generally is not toxic to most crops grown in the study area. The discharge of human, animal, or industrial wastes and irrigation return flows may add substantial quantities of chloride to ground water. Sulfate in drinking water may impart a bitter taste and act as a laxative on unacclimated users (Hem, 1985).

Nutrients and Dissolved Organic Carbon

Nutrients, containing the elements nitrogen and phosphorus, are essential for the growth and reproduction of plants. Compounds of nitrogen and phosphorus, such as synthetic fertilizers and manure, commonly are applied to cropland and some pastures to stimulate plant growth and increase crop yields and hay production. Synthetic fertilizers include anhydrous ammonia, ammonium nitrate, urea, and mono- and diammonium phosphates.

Synthetic fertilizer use in Kansas more than tripled from 1965 to 1998, from about 640,000 to about 2,100,000 tons (Kansas Department of Agriculture and U.S. Department of Agriculture, 1999), and similar increasing trends are likely in the area underlain by Quaternary deposits in south-central Kansas. Farm livestock also produce large quantities of phosphorus- and nitrogen-rich organic wastes (urine and manure) that contribute to nonpoint sources of nutrients. Leachate from these organic wastes can infiltrate into the shallow ground-water system and potentially contaminate drinking-water sources. Other sources of nutrients include human waste, nitrogen-containing organic compounds, and industrial waste. Large concentrations of nutrients (particularly nitrates) in drinking water may be physiologically damaging to humans.

Human health-based regulations have been established for nitrate concentrations in drinking water because of the potential adverse health effects on infants. Consumption of drinking water with nitrate concentrations larger than 10 mg/L can cause methemoglobinemia (blue-baby syndrome) in infants, a sometimes fatal illness related to the impairment of the oxygen-carrying ability of the blood (U.S. Environmental Protection Agency, 1986). Accordingly, an MCL of 10 mg/L of nitrate as nitrogen has been established by the USEPA and implemented at the State level by the Kansas Department of Health and Environment (1994).

Nitrite and nitrate are inorganic ions produced during various stages of the nitrogen cycle. In most oxygenated water, nitrate is the predominate ion

because of rapid oxidation of nitrite (Reid and Wood, 1976, p. 235). Nitrite and nitrate usually occur in relatively small concentrations in uncontaminated water, and concentrations in the range of several milligrams per liter suggest contamination from human activities. Mueller and Helsel (1996) estimated a national average background concentration of nitrite in ground water of 2.0 mg/L as nitrogen, which indicates that concentrations larger than 2.0 mg/L may be affected by contamination from human activities.

Concentrations of most nutrients in water from the 20 wells sampled during this study were small, with the exception of nitrite plus nitrate as nitrogen (hereinafter referred to as nitrate) ([fig. 10](#), [table 5](#) at the back of this report). Concentrations of ammonia as nitrogen ranged from less than 0.02 mg/L in water from eight wells to 0.39 mg/L (well 115). Little organic nitrogen was detected in water from wells in the study area as indicated by the similarity in ranges of concentrations for ammonia and ammonia plus organic nitrogen. Also, a similarity in ranges of concentrations for phosphorus species indicates that most phosphorus in water from wells in the study area occurs as orthophosphate. Concentrations of orthophosphate-phosphorus ranged from 0.01 to 0.26 mg/L. On average, orthophosphate-phosphorus constituted about 96 percent of the phosphorus concentration in water from the 20 wells sampled in the study area.

Concentrations of nitrate in water from the 20 wells sampled during this study varied substantially across the study area ([fig. 11](#)). Concentrations of nitrate ranged from less than 0.05 (well 115) to 15 mg/L (well 103) with a median concentration of 6.2 mg/L. Although water from well 115 had no detectable concentrations of nitrate, water from wells 103, 108, and 119 (15 percent of the sampled wells) had concentrations greater than the 10-mg/L drinking-water MCL. Generally, there is an overall enrichment of nitrate in ground water throughout the study area. This enrichment probably is the result of human-related activities. Water from 16 wells (80 percent) showed enrichment when compared to a 2.0-mg/L nitrate natural background concentration (Mueller and Helsel, 1996).

The general human-related enrichment of nitrate concentrations in water from Quaternary deposits in south-central Kansas may be a result of synthetic fertilizer applications, addition of soil amendments (manure), or livestock production. The contribution of nitrogen from fertilizers and manure applications varies substantially across the study area ([figs. 12A](#) and [12B](#)). In 1991, the average contribution of nitrogen from synthetic fertilizers in the study area varied from less than 15 lb/acre in Comanche, Hodgeman, and Rush Counties to more than 45 lb/acre in several counties ([fig. 12A](#)). A

similar variability in county-average nitrogen contributions from livestock manure is evident ([12B](#)).

A comparison of nitrogen concentrations in water from the 20 wells sampled during this study ([fig. 11](#)), with county-average nitrogen contributions from fertilizer and manure application ([figs. 12A](#) and [12B](#)) indicates that the information presented in ([figures. 12A](#) and [12B](#)) may be too geographically broad to correlate with nitrate concentrations in water from any particular well. For instance, although the small nitrate concentration in water from well 101 (Comanche County) corresponds to the relatively small county-average nitrogen contributions from fertilizer and manure, wells with water containing small nitrate concentrations (wells 107, 115, and 116) also occurred in counties (Stafford and McPherson) with much larger average nitrogen contributions. Additionally, water from some wells with larger nitrate concentrations did not correspond to the counties with some of the largest average nitrogen contributions such as water from well 104 (Pawnee County) and well 119 (Reno County).

Although county data such as that presented in ([figures. 12A](#) and [12B](#)) may help explain study-area-wide enrichment of ground water with nitrate, other more local factors also may be responsible for variability in nitrate concentrations among the sampled wells. Local factors that may affect nitrate concentrations in water from domestic wells would include the wells' proximity to fields where fertilizers and manure are applied, domestic septic systems, and livestock operations; intensity of local irrigation; annual precipitation; soil characteristics; topography; presence of relatively impermeable layers above the aquifer; and potential point-source discharges of nutrients or spills or leaks from fertilizer storage tanks.

Most uncontaminated ground water will have only small concentrations of dissolved organic carbon (DOC). In the absence of organic contamination such as leachate from landfills or spills or leaks from areas of oil and gas production, the source of DOC in ground water likely would be the end products of the biochemical cycle in the soil profile above the aquifer. These end products, generally, are humic and fulvic acids associated with the biological degradation and decay of soil-organic material or organic amendments (manure) applied to the soil. If present in large enough quantities, however, organic solutes composing DOC may form complexes that affect trace element solubility, participate in redox reactions, and affect both physical and chemical properties of solid-liquid or liquid-gas interfaces (Hem, 1985). No drinking-water quality standard has been established for DOC.

Concentrations of DOC were small in water from the 20 wells sampled during this study ([fig. 10](#), [table 5](#)). Concentrations ranged from 0.3 mg/L in water from wells 101, 102, and 111 to 1.5 mg/L in water from well 115, with a median concentration of 0.4 mg/L. However, DOC was detected at a mean concentration of 0.4 mg/L in two field-blank samples, which indicates that either sample-collection and (or) processing procedures may have introduced small concentrations of DOC or that there was an inherent bias in analytical methods. Because of the field-blank results and the small concentrations detected in the environmental samples collected from the wells, exact concentrations of DOC in water from most wells is uncertain; however, the data do indicate an upper limit (about 1.5 mg/L) of DOC in water from wells in the study area.

Trace Elements

Trace elements normally occur in natural water in small concentrations even though some are naturally abundant. For instance, although aluminum is the second-most abundant element (behind silica) in igneous and sedimentary rocks of the Earth's crust, it rarely occurs in solution in natural water in concentrations greater than a few hundred micrograms per liter (Hem, 1985). The occurrence in ground water of most of the trace elements listed in [table 4](#) (at the back of this report) typically results from natural physical and chemical processes. Physical processes include those associated with the mineral composition and origin, transport, and deposition of the aquifer material. Chemical processes include the action of water, oxygen, carbon dioxide, and other acidic components that cause the chemical breakdown or dissolution of minerals containing trace elements (Brickler and Jones, 1995, p. 1-20). Generally, the occurrence and chemical speciation of trace elements in ground water are determined by (1) hydrogen ion availability (defined by pH); (2) the presence and concentrations of inorganic ligands such as carbonate, sulfate, sulfide, and chloride; (3) the presence and concentrations of organic complexing agents (primarily humic and fulvic acids); (4) free electron availability; and (5) the ionic strength and cation distribution of the water (Allard, 1995, p. 151-176).

Human activities may affect trace-element concentrations in shallow ground water. For instance, organic and inorganic compounds of copper have been used extensively in agricultural pesticide sprays, and their wide dispersal in cropland areas has the potential to enrich copper concentrations in shallow ground water. However, the source and distribution of trace elements probably are more dominant in urban areas where trace elements such as aluminum, chromium, copper, iron, lead, nickel, and zinc are used as structural or decorative components of buildings, exterior structures and trim work, in automobiles, and as protective coverings or coatings against

corrosion and oxidation of framework or base metals. Large quantities of some trace elements have been released with effluent discharge from industrial activities, the burning of fossil fuel, and dispersed in automobile exhaust as a result of their addition to gasoline in the refining process. This potentially wide environmental distribution of trace elements creates the possibility for dissolution of some of these elements in water that, ultimately, may recharge a shallow aquifer.

Most trace elements in water from the 20 wells sampled were detected only in small concentrations that were substantially less than established MCL's ([fig. 13](#), [table 5](#) at the back of this report). In fact, the trace elements antimony, beryllium, cadmium, cobalt, lead, and silver were not detected in water from any of the wells sampled during this study. Infrequent detections of chromium (two detections), manganese (two detections), and nickel (three detections) were noted. Copper, molybdenum, selenium, uranium, and zinc were detected more frequently, but none of the detected concentrations were larger than established or proposed drinking-water standards. In contrast, aluminum and barium were detected in water from all 20 wells. Detections of trace metals such as copper, iron, and nickel in part may be the result of their use in pumps, water pipes, and plumbing fittings of domestic water-supply systems.

Few trace element concentrations exceeded respective drinking-water standards, the most notable of these is the 240- $\mu\text{g/L}$ concentration of arsenic in water from well 115 ([table 5](#)). The arsenic concentration in water from this well is 48 times the proposed 5.0- $\mu\text{g/L}$ MCL (U.S. Environmental Protection Agency, 2000b) and probably is the result of reducing conditions (dissolved-oxygen concentration of 0.1 mg/L). Arsenic is more mobile under reducing conditions than in well-oxygenated water (Hinkle, 1997). All other detected concentrations of arsenic were less than the proposed 5.0- $\mu\text{g/L}$ MCL. Potential health effects from excessive arsenic concentrations in drinking water include cardiovascular disease, diabetes, anemia, and an increased risk of cancer (U.S. Environmental Protection Agency, 2000b). Similarly, the concentration of iron in water from well 115 also was the largest (2,600 $\mu\text{g/L}$) determined in water from any of the 20 wells sampled ([table 5](#)). The concentration of iron in water from well 115 was more than eight times greater than the 300- $\mu\text{g/L}$ SMCL. Iron is an essential element in the metabolism of plants and animals; however, if present in excessive amounts, it forms red oxyhydroxide precipitates that stain laundry and plumbing fixtures and, therefore, is an objectionable impurity in domestic and industrial water supplies (Hem, 1985). Additionally, water from wells 115 and 107 had manganese concentrations greater than the 50- $\mu\text{g/L}$ SMCL, 360 and 97 $\mu\text{g/L}$ ([table 5](#)), respectively. Reducing conditions also were evident in water from well 107 (0.2 mg/L dissolved oxygen). Under reducing

conditions, manganese may be extracted (dissolved) from organic and manganese complexes or from manganese oxides. Manganese is an undesirable impurity in water supplies because of a tendency to deposit black manganese oxide stains (Hem, 1985).

Some occurrences of trace elements in ground water in the study area could originate from human-related sources as noted previously. However, the generally small concentrations that were measured probably reflect mostly natural sources for these constituents.

Pesticides

Pesticides are a group of compounds used to control unwanted plants or animals. Pesticides are applied primarily to cropland in rural areas, but also to lawns, rights-of-way, and gardens in urban areas. The widespread use of pesticides creates the potential for the movement of pesticides or their degradation products into shallow, unconfined aquifers. The presence of pesticides in ground water is a human-health concern for those using ground water as a drinking-water supply. In sufficiently large concentrations and (or) prolonged exposure, pesticides can cause human-health problems ranging from kidney and nerve damage to leukemia and other cancers (U.S. Environmental Protection Agency, 1989).

A total of 47 pesticide compounds from several classes of herbicides and insecticides that included triazine, organophosphorus, organochlorine, and carbamate compounds and three pesticide degradation products ([table 4](#) at the back of this report) were analyzed for this study at the USGS NWQL. Of the 20 wells sampled, water from 10 (50 percent) had detectable concentrations of one or more of the 47 compounds ([fig. 14](#)). The herbicide atrazine and its degradation product deethylatrazine were detected most frequently (in eight and nine samples, respectively); other detected pesticides included the insecticides carbofuran (in water from one well) and diazinon (in water from one well), and the herbicide metolachlor (in water from two wells) ([fig. 15](#)). Atrazine was detected at concentrations ranging from 0.006 to 0.18 $\mu\text{g/L}$ (in water from wells 103, 104, 105, 108, 114, 117, 118, and 119, [table 5](#) at the back of this report), and deethylatrazine was detected at estimated concentrations ranging from 0.003 to 0.11 $\mu\text{g/L}$ (in water from the same wells as atrazine plus well 113). Carbofuran was detected at an estimated concentration of 0.004 $\mu\text{g/L}$ in water from well 101; neither atrazine nor deethylatrazine were detected in water from this well ([table 5](#)). Diazinon was detected at an estimated concentration of 0.003 $\mu\text{g/L}$ in water from well 104; atrazine and deethylatrazine also were detected in water from this well. Metolachlor was detected at concentrations of 0.01 and 0.004 $\mu\text{g/L}$ in water from wells 117 and 119, respectively, which also had

detectable concentrations of atrazine and deethylatrazine. All detected concentrations of atrazine and carbofuran were substantially less than their MCL's of 3.0 and 40 µg/L, respectively; MCL's have not been established for deethylatrazine, diazinon, or metolachlor.

None of the five pesticides detected in water from the 20 wells sampled—atrazine, deethylatrazine, carbofuran, diazinon, and metolachlor—were detected in the analyses of the two organic-free (field-blank) water samples. This indicates that no contamination was introduced from previous sample collection and processing nor from laboratory processing and analysis. Analytical recoveries of atrazine, diazinon, and metolachlor determined during this study generally were better than the 79-, 70-, and 82-percent mean recoveries for atrazine, diazinon, and metolachlor, respectively, reported by Zaugg and others (1995) for spiked ground-water samples. Low recoveries of deethylatrazine and carbofuran determined during this study were consistent with the low recoveries documented by Zaugg and others (1995); as a result, all concentrations of deethylatrazine and carbofuran were reported as estimated by the USGS NWQL ([table 5](#)).

The large frequency of at least one pesticide detection (50 percent of wells sampled) in ground water in the study area indicates that land use can affect ground-water quality. Land use in the study area is predominantly agriculture ([fig. 2](#)); however, pesticide use and distribution probably are most closely associated with cropland. Although concentrations of detected pesticides were small (relative to established MCL's), the synergistic effect of these concentrations and long-term exposure to multiple pesticides on human health are unknown.

Volatile Organic Compounds

Volatile organic compounds (VOC's) are a group of relatively low molecular-weight hydrocarbons characterized by the ability to volatilize at low environmental temperatures, with high aqueous solubility, mobility, resistance to degradation, and the potential for some to have carcinogenic effects. The use or production of these compounds in industrial, manufacturing, and agricultural activities is the greatest potential source for VOC contamination of ground-water resources.

VOC's are by-products or components in the production of food, drugs, paints and varnishes, deodorants, pesticides, fumigants, glues and adhesives, rubber, cleaning agents, degreasers, disinfectants, dyes, perfumes, and many other materials. One of the major sources of VOC's is as components in fuels and motor oil. Because of the diverse uses and distribution of VOC's, the potential for ground-water contamination is

greatest in industrial or commercial areas as a result of improper disposal of industrial waste, accidental chemical spills, leaking gasoline storage tanks, or seepage from toxic-waste dumps or landfills. However, the land application of some pesticides in crop production and the use of fumigants during grain storage create the potential for movement of associated VOC's to shallow, unconfined aquifers in agricultural areas.

The presence of VOC's in ground water may pose a human-health concern for those using ground water as a drinking-water supply. In sufficiently large concentrations and (or) prolonged exposure, VOC's can cause human-health problems ranging from kidney and nerve damage to leukemia and other cancers (U.S. Environmental Protection Agency, 2000c).

Water samples from 20 domestic water-supply wells in Quaternary deposits of south-central Kansas were analyzed for 85 VOC's ([table 4](#) at the back of this report). Of the 20 wells sampled, three yielded samples with concentrations of one or more VOC's equal to or greater than the respective analytical method reporting limit ([table 5](#) at the back of this report). Chloroform was the most frequently detected VOC (in water from two wells); the only other VOC detected was styrene (in water from one well). Chloroform was detected at concentrations of 0.18 and 0.25 $\hat{\text{g}}/\text{L}$ in water from wells 111 and 115, respectively; styrene was detected at an estimated concentration of 0.045 $\hat{\text{g}}/\text{L}$ in water from well 116.

Chloroform was not detected in the analyses of the four field-blank samples; therefore, the presence of chloroform in water from wells 111 and 115 probably represents environmental occurrences of this compound. In contrast, the detection of styrene in two of the four field-blank samples (detection rate of 50 percent) indicates that styrene may be a contaminant introduced by sample collection, processing, and (or) analytical procedures. Detected concentrations of styrene in the field-blank samples were 0.14 and 0.27 $\hat{\text{g}}/\text{L}$ -similar in magnitude to the detected concentrations in environmental samples. The concentrations of chloroform and styrene were substantially less than the MCL's (100 $\hat{\text{g}}/\text{L}$) for these compounds. In summary, the occurrence and detection of VOC's in water from Quaternary deposits in south-central Kansas were infrequent, detectable concentrations were substantially less than established MCL's, and the areal distribution of VOC's in ground water was extremely limited.

Radon

Radon is a naturally occurring radioactive gas produced by the decay of the element radium. Radon, which emits ionizing radiation, occurs in drinking water and indoor air. Radon emitted by soil under homes is the primary

source of radon in indoor air. Breathing radon from indoor air in homes poses a substantial public-health risk, and as a result of radon exposure, an estimated 20,000 lung-cancer deaths occur each year in the United States (U.S. Environmental Protection Agency, 1999).

Radon from drinking water is a lesser source of radon to indoor air. Only about 1 to 2 percent of radon in indoor air comes from drinking water (U.S. Environmental Protection Agency, 1999). However, this additional source of radon to indoor air may, over a lifetime, increase the risk of lung cancer. Consumption of radon in contaminated drinking water also may increase the risk of cancers of internal organs, primarily stomach cancer. Currently (2000), no MCL has been established for radon in drinking water; however, a proposed MCL of 300 pCi/L (picocuries per liter) for radon is under review by USEPA (U.S. Environmental Protection Agency, 1999).

Concentrations of radon were detected in water from every well sampled for this study and ranged from 200 (well 101) to 590 pCi/L (well 115) ([table 5](#) at the back of this report), with a median concentration of 260 pCi/L. Although the median concentration of radon is less than the proposed MCL of 300 pCi/L, water from six wells (30 percent) contained radon in concentrations larger than the proposed MCL.

Summary

Knowledge of the quality of the Nation's water resources is important because of the implications to human and aquatic health and because of substantial costs associated with land and water management, conservation, and regulation. In 1991, the U.S. Geological Survey began full implementation of the National Water-Quality Assessment (NAWQA) Program. The long-term goals of the NAWQA Program are to describe the status and trends in the quality of the Nation's surface- and ground-water resources and to determine the natural and human-related factors affecting water quality.

The High Plains Regional Ground-Water Study was begun in June 1998 and represents a modification of the traditional NAWQA design in that the ground-water resource is the primary focus of investigation. The High Plains aquifer is a nationally important water resource that underlies about 174,000 mi² in parts of eight Western States. About 20 percent of agricultural land in the United States is in the High Plains, and about 30 percent of all the ground water used for irrigation in the United States is pumped from this aquifer.

The Quaternary deposits of south-central Kansas constitute a 7,000-mi² hydrogeologic subunit of the High Plains aquifer and provide water for irrigation and serve as a major drinking-water supply for the area. Generally, the deposits consist of unconsolidated sand and gravel with thin, interspersed layers of silt and clay. Water in the deposits is derived mainly from recharge of precipitation and irrigation return flow, although the density of irrigation withdrawals from Quaternary deposits in south-central Kansas is much less than from other areas of the High Plains aquifer. Water in the Quaternary deposits is vulnerable to effects from land-surface activities.

Land use overlying the Quaternary deposits of south-central Kansas is typical of this major agricultural region in the Midwestern United States. Cropland and grassland (pasture and rangeland) dominate the area. Major crops include corn, sorghum, soybeans, sunflowers, and wheat. Grassland in the area generally is used, directly or indirectly, for livestock production. Much of the grassland is pasture or rangeland used for cattle and calf production. Areas not used for pasture typically are used for hay production, which is subsequently used as winter feed for cattle on rangeland or in confined feeding operations.

Water samples from 20 randomly selected domestic water-supply wells were analyzed for about 170 water-quality constituents including physical properties, dissolved solids and major ions, nutrients and dissolved organic carbon, trace elements, pesticides, volatile organic compounds (VOC's), and radon. Many of the constituents from these compound classes are regulated in public drinking-water supplies by the U.S. Environmental Protection Agency (USEPA). Sampled well depths ranged from 50 to 160 ft. Depths to water ranged from about 12 to about 93 ft below land surface, with a median depth of about 30 ft.

Physical properties were measured in water from each of the 20 domestic water-supply wells sampled during this study. Measurements made at the time of sample collection included specific conductance, pH, water temperature, turbidity, dissolved oxygen, and alkalinity. Water from most wells had specific conductance values less than 800 $\mu\text{S}/\text{cm}$ (microsiemens per centimeter at 25 \div C). Water from only three wells had specific conductance values greater than 800 $\mu\text{S}/\text{cm}$, the largest of which was 1,760 $\mu\text{S}/\text{cm}$. The pH of water from all sampled wells was within the Secondary Maximum Contaminant Level (SMCL) range of 6.5 to 8.5 standard units with the exception of water from one well which had a pH of 6.4. The turbidity of water from all wells was low, which indicated acceptable aesthetic qualities, a lack of obvious contamination, and that the wells were developed properly and the samples were representative of the aquifer water. Water from most

of the wells was well oxygenated as indicated by a median dissolved-oxygen concentration of 5.1 mg/L (milligrams per liter). Water from two wells, however, had unusually small dissolved-oxygen concentrations (0.2 and 0.1 mg/L). Alkalinity as CaCO₃ ranged from 60 to 320 mg/L.

Concentrations of dissolved solids in water from the 20 sampled wells ranged from 143 to 1,060 mg/L. The median dissolved-solids concentration was 318 mg/L, substantially less than the 500-mg/L SMCL. However, water from five wells did exceed this secondary standard and probably is the result of dissolved solids from natural processes.

Generally, the data collected for this study indicate that calcium bicarbonate type water is the dominant ground-water type in the Quaternary deposits of south-central Kansas. However, this water chemistry can be modified locally by the introduction of sodium chloride type water, a mixed-water type of calcium bicarbonate sulfate and sodium chloride, or a calcium and magnesium sulfate type water. The SMCL's (250 mg/L) for chloride and sulfate were exceeded in water from one well each. The source of this chloride and sulfate was probably from natural processes.

Concentrations of most nutrients in water from the 20 sampled wells were small, with the exception of nitrate. Concentrations of nitrate as nitrogen ranged from less than 0.05 to 15 mg/L, with a median concentration of 6.2 mg/L. Water from 15 percent of the sampled wells had concentrations of nitrate greater than the 10-mg/L drinking-water Maximum Contaminant Level (MCL). Generally, there is an overall enrichment of nitrate in ground water throughout the Quaternary deposits in the study area. This enrichment probably is the result of human-related activities. Water from 80 percent of the sampled wells showed nitrate enrichment, which is more than what might be expected for natural background concentrations (2.0 mg/L). This enrichment may be the result of synthetic fertilizer applications, the addition of soil amendments (manure) on cropland, or livestock production.

Concentrations of dissolved organic carbon (DOC) were small in water from the 20 sampled wells. Concentrations ranged from 0.3 to 1.5 mg/L. However, DOC was detected at a mean concentration of 0.4 mg/L in two field-blank samples, which indicates that either sample-collection and (or) processing procedures contaminated the samples or there was an inherent bias in the analytical methods.

Most detected trace elements in water from the 20 sampled wells occurred only in small concentrations and were substantially less than established MCL's. The trace elements antimony, beryllium, cadmium, cobalt, lead, and silver were not detected in water from any of the wells sampled during this

study. Infrequent detections of chromium (two detections), manganese (two detections), and nickel (three detections) were noted. Copper, molybdenum, selenium, uranium, and zinc were detected more frequently, but none of the detected concentrations were larger than established or proposed drinking-water standards. In contrast, aluminum and barium were detected in water from all 20 wells.

Few trace-element concentrations exceeded respective drinking-water standards. Only arsenic was detected (in one well sample) at a concentration (240 $\mu\text{g/L}$, micrograms per liter) that exceeds the proposed MCL (5.0 $\mu\text{g/L}$). All other detected concentrations of arsenic were less than the proposed MCL. Additionally, one concentration of iron and two concentrations of manganese were larger than the respective SMCL's of 300 and 50 $\mu\text{g/L}$. Exceedances of drinking-water standards for arsenic, iron, and manganese were associated with well locations where water in the Quaternary deposits was under reducing (nonoxygenated) conditions.

Some occurrences of trace elements in ground water in the study area could originate from human-related sources. However, the generally small concentrations that were measured probably reflect mostly natural sources for these constituents.

A total of 47 pesticide compounds from several classes of herbicides and insecticides that included triazine, organophosphorus, organochlorine, and carbamate compounds and three pesticide degradation products were analyzed in ground-water samples. Of the 20 wells sampled, water from 10 (50 percent) had detectable concentrations of one or more of these 47 compounds. The herbicide atrazine and its degradation product deethylatrazine were detected the most frequently (in water from eight and nine wells, respectively); other detected pesticides included the insecticides carbofuran (in water from one well) and diazinon (in water from one well), and the herbicide metolachlor (in water from two wells). All detected concentrations of atrazine and carbofuran were substantially less than their MCL's of 3.0 and 40 $\mu\text{g/L}$, respectively; MCL's have not been established for deethylatrazine, diazinon, or metolachlor.

Agricultural activities, particularly those associated with crop production, probably are responsible for the occurrence of pesticides in ground water in the study area. Although concentrations of detected pesticides were small, the synergistic effect of these concentrations and long-term exposure to multiple pesticides on human health are unknown.

Water samples were analyzed for 85 volatile organic compounds (VOC's). Of the 20 wells sampled, water from three had detectable concentrations of one

or more VOC's. Chloroform was the most frequently detected VOC (in two samples); styrene was detected in one sample. Analytical results from field-blank samples indicated that styrene was probably a contaminant associated with sample collection, processing, and (or) analytical procedures. In general, the occurrence and detection of VOC's in water from Quaternary deposits in south-central Kansas were infrequent, detectable concentrations were substantially less than established MCL's, and the areal distribution of VOC's in ground water was extremely limited.

Concentrations of radon were detected in water from every well sampled and ranged from 200 to 590 pCi/L (picocuries per liter), with a median concentration of 260 pCi/L. Although the median concentration of radon is less than the proposed MCL of 300 pCi/L, water from six wells (30 percent) contained radon in concentrations larger than this proposed standard.

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SUPPLEMENTAL INFORMATION

[Table 4.](#) Water-quality constituents analyzed in water samples from domestic water-supply wells completed in Quaternary deposits, south-central Kansas, 1999 [Table 5.](#) Results of physical and chemical analyses of water samples from domestic water-supply wells completed in Quaternary deposits, south-central Kansas, 1999

For additional information, please write or call:

U.S. Geological Survey
4821 Quail Crest Place
Lawrence, KS 66049-3839
Telephone: (785) 842-9909
FAX: (785) 832-3500
email: GS-W-KS_info@usgs.gov